Load Flow And Contingency Studies For The Nigeria 31-Bus 330-Kv Power System

Onaopemipo Taiwo

Abstract: It is desirable for an electric network to be 100% efficient, in which case the total power generated in the network equals the total power consumed. However, due to the presence of impedances in transmission lines connecting buses as well as Transformer windings, some inevitable power losses are incurred. It becomes necessary to bring these losses to their lowest ebb to reduce the cost of generating power as well as improve the overall efficiency of the network. In this vein, the 330-kV, Nigerian 31-Bus system has been selected for power flow analysis. A careful observation of this system shows that some bus voltages are below the permitted voltage limit of 0.95pu-1.05pu (313.5kV-346.5kV). Kano (0.7193pu), Gombe(0.7961pu), Jos (0.8123pu), Katampe (0.9044pu), Kaduna (0.8530pu), Yola (0.7975pu) and Jalingo (0.7917pu) are buses that have violated this limit. Kano bus (0.7193pu) has the lowest voltage because it has a large load and is far from Generator buses. The essence of this analysis is to use tap changing Transformers as well as Capacitive and Inductive shunt compensators to improve the bus voltages to acceptable values while bringing the total power losses to the barest minimum. The method employed in this power flow analysis is the Newton-Rapson (N-R) iterative technique written in code-based "R".

Keywords: Compensators, Efficiency, Power flow analysis, Power loss, Tap Changing Transformers, Transmission lines, Voltage limit

1 INTRODUCTION

Like any other electric network, the Nigerian 330-kV, 31-Bus system is composed of Transmission lines, Transformers, Generators and electric loads all interconnected. However, due to the long lengths of transmission lines as well as the presence of large loads on buses, bus voltages drop below considerable limits. With a reduction in bus voltages, losses are introduced into the system. A successful power system operation under normal balanced three-phase steady state condition requires that:

- Generator supplies equals demand and losses.
- Bus voltage magnitudes remain close to the rated values.
- Generators operate within specified real and reactive power limits
- Transmission lines and Transformers are not overloaded.

The network system is bedevilled with a real power loss of 116MW representing 2.74% of the 4241MW generated. A measure must be put in place to reduce this loss. While it is practically impossible to reduce the transmission line lengths between buses to avoid voltage drops, Capacitive compensations as well as Tap Changing Transformers can be used to improve voltage profiles at buses. While capacitive reactance is injected at low voltage profile buses to improve voltage profiles on a bus, the resultant effect of the capacitive compensation is felt on other nearby voltage buses. Tap changing Transformers have taps attached to the secondary windings which help to vary output voltages. With the inclusion of tap changing transformers on transmission lines, voltage profiles of buses located at the ends of the line would be improved. Because of an improvement in voltage profiles, power losses in electric power networks reduces.

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2 METHODOLOGY

As stated previously, the Nigerian 31-Bus system would be subjected to contingency analysis using Newton-Rapson (N-R) iterative technique written in code-based "R". Buses which violate the limit (0.95pu-1.05pu) would be identified and compensators (capacitive or inductive) would be injected at each violating bus to either increase ($V_{bus} < 0.95pu$) or decrease ($V_{bus} > 0.95pu$) the voltage profiles. Tap changing transformers would also be installed along transmission lines to further bring the voltage profiles to the rated values of 1pu (330kV). By so doing, the power loss would be reduced. The line diagram of the Nigerian 330-kV, 31-Bus system (as obtained from RpowerLABS) used as a case study is shown in Fig. 1

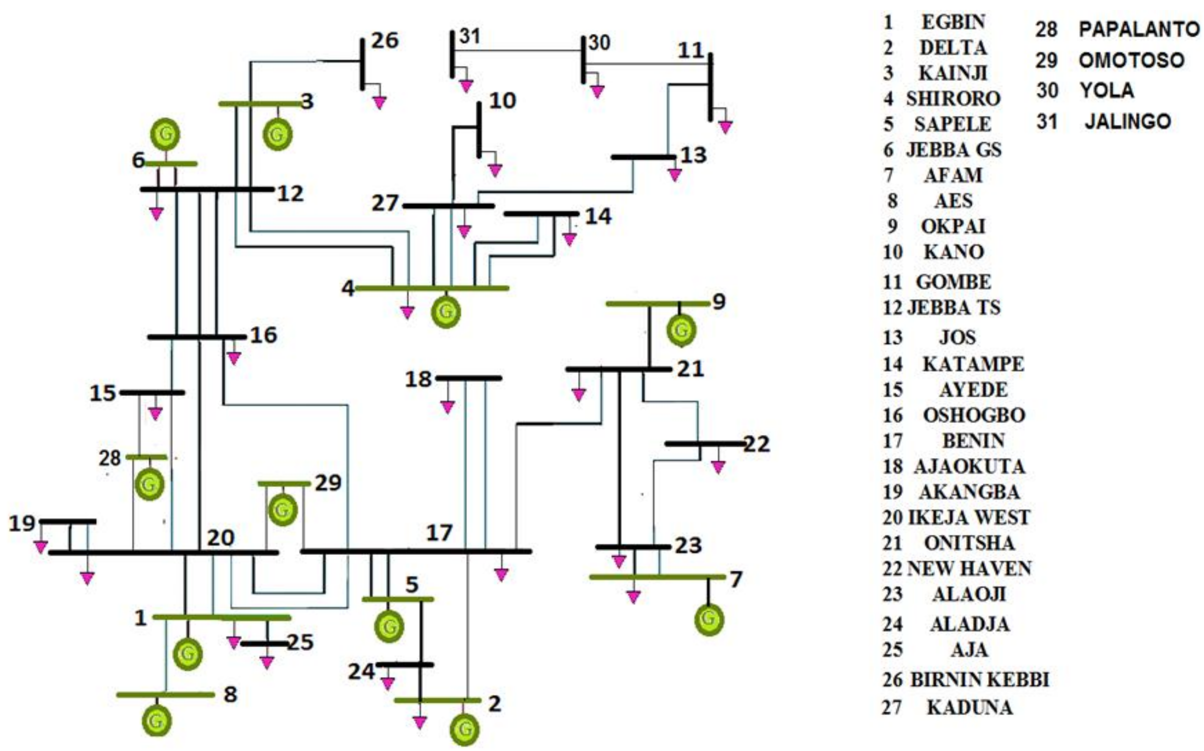

Fig. 1: *The single line diagram of the 31-Bus, 330kV power network*

3 RESULTS AND DISCUSSIONS

3.1 THE NIGERIA-31 BUS SYSTEM

A summary of the Network gives the number of lines, load buses and generator buses to be; 44, 20 and 11 respectively. Table 1 presents the voltage magnitudes, the real and reactive power generated as well as the real and reactive loads in the system before contingency analysis.

Table 1: *Power Flow Simulation (before compensation) by N-R*

Bus	Voltage (p.u)	Angle (deg.)	Gen.Power(MW)	Gen.Power(Mvar)	Load(MW)	Load(Mvar)
1	1	0	1101	285.586	260	129.58
2	1	-4.332	338	-38.251	44	21.923
3	1	-10.79	290	-70.219	0	0
4	0.95	-29.684	530	668.274	120	59.81
5	1	-5.98	77	-68.871	0	0
6	1	-13.177	415	67.331	0	0
7	1	-2.157	363	77.373	64	31.898
8	1	2.99	237.1	1.553	0	0
9	1	-4.524	298	-20.531	0	0
10	0.719	-51.378	0	0	200	112.64
11	0.796	-61.622	0	0	80	39.872
12	0.997	-13.69	0	0	12	5.981
13	0.812	-50.598	0	0	80	39.87
14	0.904	-34.388	0	0	185	92.204
15	0.984	-10.69	0	0	240	119.62
16	0.994	-12.228	0	0	180	89.712

17	1.002	-6.523	0	0	120	59.81
18	1.018	-6.872	0	0	15	7.476
19	0.959	-10.736	0	0	400	199.36
20	0.98	-8.757	0	0	550	274.12
21	0.975	-5.836	0	0	152	75.757
22	0.953	-8.158	0	0	135	67.284
23	0.97	-3.128	0	0	250	124.6
24	1	-5.389	0	0	43	21.43
25	0.98	-1.898	0	0	200	99.68
26	0.994	-15.455	0	0	85	42.364
27	0.853	-38.942	0	0	490	244.22
28	1	-8.265	504	330.203	150	70
29	1	-6.443	88.3	-18.783	0	0
30	0.797	-65.891	0	0	30	15.8
31	0.792	-67.321	0	0	40	19.4

Table 2 presents the transmission line flows and losses present in the network before contingency analysis.

Table 2: *Summary of the power flow results (before compensation) using N-R*

From Bus	To Bus	Real Power flow (MW)	Reactive Power flow (Mvar)	Apparent Power flow (KVA)	Real Power loss (MW)	Reactive Power loss (Mvar)
1	20	876.436	60.941	878.552	17.012	111.76
1	25	201.101	87.049	219.132	1.101	-12.631
1	8	-236.931	8.017	237.067	0.169	9.57
2	17	197.753	-43.183	202.413	0.925	-12.572
2	24	96.247	-16.992	97.735	0.214	-18.376
3	26	85.817	-49.396	99.018	0.817	-91.76
3	12	204.183	-20.823	205.242	1.211	-15.639
4	27	480.877	281.897	557.412	12.007	78.095
4	27	480.877	281.897	557.412	12.007	78.095
4	14	187.502	68.139	199.499	2.502	-24.065
4	12	-369.628	-11.734	369.814	10.184	32.565
4	12	-369.628	-11.734	369.814	10.184	32.565
5	17	64.983	-34.663	73.65	0.088	-16.903
5	17	64.983	-34.663	73.65	0.088	-16.903
5	24	-52.965	0.454	52.967	0.067	-19.591
6	12	415	67.331	420.427	0.531	1.1
7	23	299	45.475	302.438	8.27	-2.067
8	1	237.1	1.553	237.105	0.169	9.57
9	21	298	-20.531	298.706	8.016	-2.305
10	27	-200	-112.64	229.538	7.729	20.009
11	13	-150.745	-10.53	151.113	3.447	-25.7
11	30	70.745	-29.342	76.589	0.622	-38.882

12	16	-51.394	-11.177	52.595	0.16	-48.537
12	16	-51.394	-11.177	52.595	0.16	-48.537
12	16	-51.394	-11.177	52.595	0.16	-48.537
12	4	379.811	44.299	382.386	10.184	32.565
12	4	379.811	44.299	382.386	10.184	32.565
12	6	-414.469	-66.231	419.728	0.531	1.1
12	3	-202.972	5.185	203.038	1.211	-15.639
13	27	-234.192	-24.7	235.491	5.819	6.034
13	11	154.192	-15.17	154.936	3.447	-25.7
14	4	-185	-92.204	206.704	2.502	-24.065
15	20	-75.841	-1.46	75.855	0.311	-39.716
15	16	70.976	-53.439	88.845	0.267	-33.75
15	28	-235.135	-64.722	243.88	1.266	-7.938
16	17	-128.592	-29.477	131.927	1.499	-67.293
16	20	-135.359	32.154	139.126	1.053	-33.854
16	12	51.554	-37.359	63.667	0.16	-48.537
16	12	51.554	-37.359	63.667	0.16	-48.537
16	12	51.554	-37.359	63.667	0.16	-48.537
16	15	-70.709	19.689	73.399	0.267	-33.75
17	16	130.092	-37.816	135.477	1.499	-67.293
17	21	-19.948	47.693	51.697	0.257	-40.766
17	21	-19.948	47.693	51.697	0.257	-40.766
17	5	-64.895	17.759	67.281	0.088	-16.903
17	5	-64.895	17.759	67.281	0.088	-16.903
17	2	-196.829	30.611	199.195	0.925	-12.572
17	18	7.56	-59.886	60.361	0.06	-63.624
17	18	7.56	-59.886	60.361	0.06	-63.624
17	20	52.154	-25.782	58.178	0.325	-93.728
17	20	52.154	-25.782	58.178	0.325	-93.728
17	29	-3.004	-12.173	12.538	0.003	-38.533
18	17	-7.5	-3.738	8.38	0.06	-63.624
18	17	-7.5	-3.738	8.38	0.06	-63.624
19	20	-200	-99.68	223.464	1.151	-11.37
19	20	-200	-99.68	223.464	1.151	-11.37
20	17	-51.828	-67.946	85.456	0.325	-93.728
20	17	-51.828	-67.946	85.456	0.325	-93.728
20	1	-859.424	50.819	860.925	17.012	111.76
20	16	136.412	-66.008	151.543	1.053	-33.854
20	15	76.152	-38.256	85.222	0.311	-39.716
20	19	201.151	88.31	219.682	1.151	-11.37
20	19	201.151	88.31	219.682	1.151	-11.37
20	29	-84.816	-53.76	100.418	0.478	-46.182
20	28	-116.97	-207.643	238.322	0.629	-4.223
21	23	-38.215	37.454	53.509	2.515	-39.603
21	22	135.789	45.48	143.203	0.789	-21.804

21	9	-289.984	18.226	290.556	8.016	-2.305
21	17	20.205	-88.459	90.737	0.257	-40.766
21	17	20.205	-88.459	90.737	0.257	-40.766
22	21	-135	-67.284	150.838	0.789	-21.804
23	21	40.73	-77.058	87.16	2.515	-39.603
23	7	-290.73	-47.542	294.592	8.27	-2.067
24	5	53.033	-20.046	56.695	0.067	-19.591
24	2	-96.033	-1.384	96.043	0.214	-18.376
25	1	-200	-99.68	223.464	1.101	-12.631
26	3	-85	-42.364	94.972	0.817	-91.76
27	4	-468.87	-203.801	511.247	12.007	78.095
27	4	-468.87	-203.801	511.247	12.007	78.095
27	13	240.011	30.733	241.971	5.819	6.034
27	10	207.729	132.649	246.469	7.729	20.009
28	15	236.401	56.783	243.125	1.266	-7.938
28	20	117.599	203.419	234.966	0.629	-4.223
29	20	85.293	7.577	85.629	0.478	-46.182
29	17	3.007	-26.361	26.532	0.003	-38.533
30	11	-70.123	-9.54	70.769	0.622	-38.882
30	31	40.123	-6.26	40.608	0.123	-25.66
31	30	-40	-19.4	44.456	0.123	-25.66
TOTAL					**116**	**-850.746**

3.2 NETWORK IMPROVEMENT USING COMPENSATORS AND TAP CHANGERS

In order to improve the efficiency of the network, a mixture of Tap changing Transformers as well as reactive capacitances would be used along transmission lines as well as at buses with low voltage profiles. The affected buses have been identified as Kano, Gombe, Jos, Katampe, Kaduna, Yola and Jalingo. While capacitive reactance would be injected at some of these buses (Kano and Kaduna), an inductive reactance (negative Mvar) would be injected at some other buses (Gombe and Yola) to reduce the voltage magnitudes that have risen above limits (0.95pu – 1.05pu). An injection of 200Mvar and 10Mvar at Kano and Kaduna buses respectively increases the voltage profiles of Gombe and Yola buses to 1.08pu and 1.09pu respectively which are above limit. Also, to reduce transmission losses, tap changers were introduced along lines; 30 (connecting buses 20-27), 32 (connecting buses 14 and 4) and 3 (connecting buses 21 and 22). Table 3 summarizes the compensations installed to reduced transmission losses.

Table 3: *Values of injected Mvar and tap positions at buses*

Bus	Reactance injected (Mvar)	Lines	Tap position
10	200	3	0.95
11	-22		
19	350	30	0.95
22	50		
23	100	32	1.025
27	10		
30	-1		

The effects of installing compensations at buses and along the transmission lines are summarized in table 4.

Table 4: *Power Flow Simulation (after compensation) by N-R*

Bus	Voltage (p.u)	Angle (deg.)	Gen.Power(MW)	Gen.Power(Mvar)	Load(MW)	Load(Mvar)
1	1	0	1081	196.189	260	129.6
2	1	-3.989	338	-49.583	44	21.92
3	1	-10.08	290	-83.262	0	0
4	1	-28.04	530	333.133	120	59.81
5	1	-5.635	77	-99.939	0	0
6	1	-12.45	415	-79.03	0	0
7	1	-1.561	363	-16.727	64	31.9
8	1	2.99	237.1	1.553	0	0
9	1	-3.929	298	-73.927	0	0
10	0.975	-44.72	0	0	200	112.6
11	1.008	-52.14	0	0	80	39.87
12	1	-12.99	0	0	12	5.981
13	0.985	-44.76	0	0	80	39.87
14	0.983	-32.27	0	0	185	92.2
15	0.989	-10.32	0	0	240	119.6
16	1	-11.71	0	0	180	89.71
17	1.004	-6.192	0	0	120	59.81
18	1.02	-6.54	0	0	15	7.476
19	1.005	-10.62	0	0	400	199.4
20	0.995	-8.543	0	0	550	274.1
21	0.978	-5.517	0	0	152	75.76
22	1.024	-7.657	0	0	135	67.28
23	0.977	-3.023	0	0	250	124.6
24	0.999	-5.046	0	0	43	21.43
25	0.979	-1.898	0	0	200	99.68
26	0.994	-14.74	0	0	85	42.36
27	0.97	-36.07	0	0	490	244.2
28	1	-7.926	504	132.271	150	70
29	1	-6.125	88.3	-56.251	0	0
30	1.031	-54.88	0	0	30	15.8
31	1.03	-55.75	0	0	40	19.4

Table 5 presents the transmission line flows and losses present in the network after contingency analysis.

Table 5: *Summary of the power flow results (after compensation) using N-R*

From Bus	To Bus	Real Power flow (MW)	Reactive Power flow (Mvar)	Apparent Power flow (KVA)	Real Power loss (MW)	Reactive Power loss (Mvar)
1	20	857.312	-22.46	857.784	16.176	104.894
1	25	201.101	87.049	219.132	1.101	-12.631
1	8	-236.93	8.017	237.067	0.169	9.57
2	17	197.878	-54.53	205.253	0.946	-12.439

2	24	96.122	-16.98	97.61	0.214	-18.381
3	26	85.817	-49.4	99.018	0.817	-91.76
3	12	204.183	-33.87	206.972	1.222	-15.63
4	27	473.61	63.202	477.808	7.836	37.492
4	27	473.61	63.202	477.808	7.836	37.492
4	14	187.196	59.597	196.454	2.196	-31.434
4	12	-362.21	43.661	364.83	9.249	18.705
4	12	-362.21	43.661	364.83	9.249	18.705
5	17	64.921	-50.19	82.058	0.107	-16.797
5	17	64.921	-50.19	82.058	0.107	-16.797
5	24	-52.841	0.436	52.843	0.067	-19.594
6	12	415	-79.03	422.458	0.535	1.12
7	23	299	-48.63	302.928	8.222	-2.161
8	1	237.1	1.553	237.105	0.169	9.57
9	21	298	-73.93	307.033	8.428	-2.018
10	27	-200	83.572	216.759	4.277	-37.105
11	13	-150.58	14.272	151.256	2.427	-63.907
11	30	70.581	-76.14	103.824	0.509	-68.021
12	16	-45.829	-18.15	49.293	0.12	-49.339
12	16	-45.829	-18.15	49.293	0.12	-49.339
12	16	-45.829	-18.15	49.293	0.12	-49.339
12	4	371.456	-24.96	372.294	9.249	18.705
12	4	371.456	-24.96	372.294	9.249	18.705
12	6	-414.47	80.15	422.144	0.535	1.12
12	3	-202.96	18.237	203.779	1.222	-15.63
13	27	-233.01	38.309	236.136	4.262	-23.814
13	11	153.008	-78.18	171.824	2.427	-63.907
14	4	-185	-91.03	206.184	2.196	-31.434
15	20	-73.995	-26.31	78.532	0.275	-40.913
15	16	64.39	-55.69	85.134	0.233	-34.451
15	28	-230.4	-37.62	233.446	1.157	-8.986
16	17	-124.97	-25.66	127.578	1.409	-68.732
16	20	-128.72	8.269	128.985	0.857	-36.455
16	12	45.949	-31.19	55.534	0.12	-49.339
16	12	45.949	-31.19	55.534	0.12	-49.339
16	12	45.949	-31.19	55.534	0.12	-49.339
16	15	-64.157	21.241	67.582	0.233	-34.451
17	16	126.38	-43.07	133.518	1.409	-68.732
17	21	-20.08	43.656	48.053	0.23	-41.254
17	21	-20.08	43.656	48.053	0.23	-41.254
17	5	-64.814	33.39	72.909	0.107	-16.797
17	5	-64.814	33.39	72.909	0.107	-16.797
17	2	-196.93	42.087	201.379	0.946	-12.439
17	18	7.56	-60.16	60.634	0.06	-63.899
17	18	7.56	-60.16	60.634	0.06	-63.899

17	20	53.465	-43.08	68.658	0.287	-95.73
17	20	53.465	-43.08	68.658	0.287	-95.73
17	29	-1.71	-6.445	6.668	0.007	-38.577
18	17	-7.5	-3.738	8.38	0.06	-63.899
18	17	-7.5	-3.738	8.38	0.06	-63.899
19	20	-200	75.32	213.713	1.033	-13.604
19	20	-200	75.32	213.713	1.033	-13.604
20	17	-53.178	-52.66	74.836	0.287	-95.73
20	17	-53.178	-52.66	74.836	0.287	-95.73
20	1	-841.14	133.35	851.64	16.176	104.894
20	16	129.576	-44.72	137.077	0.857	-36.455
20	15	74.27	-14.61	75.693	0.275	-40.913
20	19	201.033	-88.92	219.822	1.033	-13.604
20	19	201.033	-88.92	219.822	1.033	-13.604
20	29	-86.155	-23.27	89.243	0.427	-47.391
20	28	-122.27	-41.71	129.186	0.181	-8.075
21	23	-38.639	30.682	49.339	2.139	-40.382
21	22	135.591	-10.12	135.968	0.591	-27.403
21	9	-289.57	71.909	298.367	8.428	-2.018
21	17	20.31	-84.91	87.305	0.23	-41.254
21	17	20.31	-84.91	87.305	0.23	-41.254
22	21	-135	-17.28	136.102	0.591	-27.403
23	21	40.778	-71.06	81.932	2.139	-40.382
23	7	-290.78	46.464	294.467	8.222	-2.161
24	5	52.908	-20.03	56.573	0.067	-19.594
24	2	-95.908	-1.4	95.918	0.214	-18.381
25	1	-200	-99.68	223.464	1.101	-12.631
26	3	-85	-42.36	94.972	0.817	-91.76
27	4	-465.77	-25.71	466.482	7.836	37.492
27	4	-465.77	-25.71	466.482	7.836	37.492
27	13	237.27	-62.12	245.268	4.262	-23.814
27	10	204.277	-120.7	237.259	4.277	-37.105
28	15	231.552	28.634	233.316	1.157	-8.986
28	20	122.448	33.637	126.984	0.181	-8.075
29	20	86.583	-24.12	89.88	0.427	-47.391
29	17	1.717	-32.13	32.178	0.007	-38.577
30	11	-70.071	8.123	70.541	0.509	-68.021
30	31	40.071	-24.92	47.19	0.071	-44.323
31	30	-40	-19.4	44.456	0.071	-44.323
TOTAL					**96.881**	**-1177.2**

As seen in Table 4, the introduction of shunt capacitors and tap changers at some buses and along transmission lines have improved bus voltages to acceptable limits ($0.95pu < V_{bus} < 1.05pu$). Table 5 shows a reduction in transmission line losses as a result of installing compensations. Before the installation of compensations, the line losses were 116MW and -850.746Mvar for the real and reactive powers respectively. On the installation of compensations, the real and reactive losses reduced to 96.88MW and -1177.191Mvar respectively. Another observation is that the real and reactive powers generated in the network have been reduced. The real and reactive powers were 4241.005MW and 1213.64MVAR respectively (before compensation). However, after the installation of compensations, the real and reactive powers generated reduced to 4221.88MW and 204.4259MVAR respectively. The implication of this is that 19.125MW of electricity has been conserved without load shedding (the total load in the network remains 4125MW and 2064.411MVAR for real and reactive loads respectively). According to https://www.export.gov/article?id=Nigeria-Electrical-Power-Equipment, the government of Nigeria estimates that by 2020, an additional 26,600MW of additional supply would be required to meet demand. An investment of $4 billion is required for the supply of electricity to meet the demand. Going by these figures, 19.125MW of electricity generation would cost $2.88 Million.

4 CONCLUSION

In order to save cost, improve transmission line capacity and reliability and efficiency, extend the useful lives of Transformers, reduce transmission line losses and prevent sudden network collapse, compensations in form of Capacitive reactance as well as Tap changers should be installed in the Nigerian 31-Bus, 330kV transmission line network. As proven, 19.125MW power conservation would save the government of Nigeria a sum of $2.88 Million which can be used to support other sectors of the economy in terms of funding. Furthermore, since the efficiency of any electricity network is determined by the percentage of the generated power that is consumed by the load, it suffices to say that there has been an improvement of 0.46% (97.24% to 97.7%) in the efficiency of the network.

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